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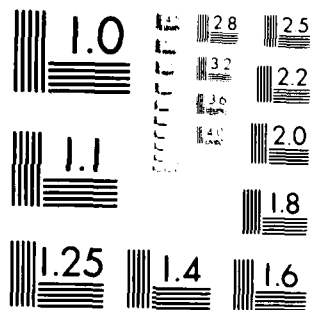
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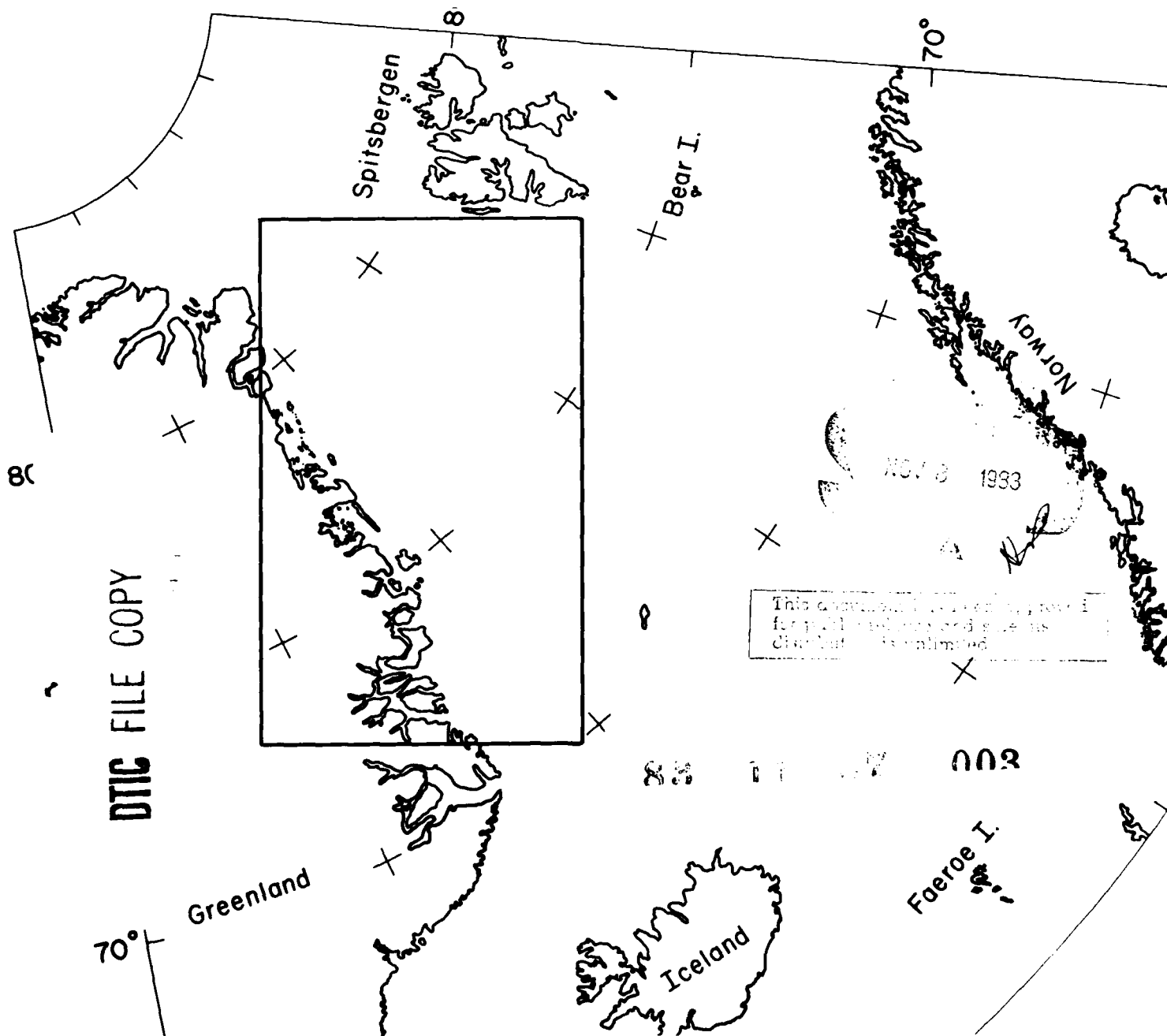
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US Army Corps  
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Cold Regions Research &  
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*A comparison of sea ice model results  
using three different wind forcing fields*



*For conversion of SI metric units to U.S./British customary units of measurement consult ASTM Standard E380, Metric Practice Guide, published by the American Society for Testing and Materials, 1916 Race St., Philadelphia, Pa. 19103.*

*Cover: Rectangular box encloses area of sea ice model studies.*



# CRREL Report 83-17

June 1983

## *A comparison of sea ice model results using three different wind forcing fields*

Walter B. Tucker III

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20. Abstract (cont'd).

land stations and from manual digitization of the NWS hand-analyzed Northern Hemisphere Surface Charts. Modeling results using winds derived from both of these fields agreed favorably.

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## PREFACE

This report was prepared by Walter B. Tucker III, Geologist, Snow and Ice Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory.

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# A COMPARISON OF SEA ICE MODEL RESULTS USING THREE DIFFERENT WIND FORCING FIELDS

Walter B. Tucker III

## INTRODUCTION

The Greenland Sea contains a marginal ice zone (MIZ) that is bounded on the east by open ocean and on the west by Greenland. In a recent study, a numerical sea ice model (Tucker and Hibler 1981, Tucker 1982) was applied to this area to assess the model's ability to simulate reasonably the ice drift, deformation, and growth processes in a MIZ on a relatively small scale. Previous Northern Hemisphere ice modeling studies have concentrated on the Arctic Basin and its coastal areas (Hibler 1979, 1980a; Pritchard 1980). Other reasons for applying the model to the Greenland Sea were to evaluate the sensitivity of ice transport and extent to various driving forces (winds, currents, and thermodynamic variables) and to determine whether internal ice stress is an important component of the ice momentum balance in this region. Tucker (1982) describes the results of this investigation in detail.

The dynamic-thermodynamic sea ice model employed in the study was developed by Hibler (1979). Basic components of the model include a momentum balance, a constitutive law that relates ice stress to ice strength and strain rate, an ice thickness distribution, and a strength parameterization that relates strength to the thickness distribution. In addition, a thermodynamic model calculates ice growth rates from a surface energy balance equation. Hibler has described this thermodynamic model (1980a) and has documented the

numerical code for the ice dynamics (1980b). Tucker (1982) applied the model to a 40-km grid for a 60-day period incremented at  $\frac{1}{4}$ -day (21,600-s) time steps.

External driving fields for the model are geostrophic winds, geostrophic ocean currents, surface temperature, and humidity. Simple quadratic drag laws are used to calculate the air and water stress terms in the momentum equation from the geostrophic winds and currents. The geostrophic winds are calculated from sea-level pressures (SLPs) that have been interpolated to the model grid. For the previous investigation (Tucker 1982), sea level pressures, temperatures, and relative humidities were obtained from the National Climatic Center (NCC). The data were analysis fields in a  $2\frac{1}{2}$ -degree Northern Hemisphere grid. The desired fields were in packed binary format on tape; each tape contained approximately two weeks of data, normally for 0000Z and 1200Z each day. Pressures were extracted for 1200Z, then interpolated to the remaining  $\frac{1}{4}$ -day intervals, primarily because the  $\frac{1}{4}$ -day time step stability requirement was not foreseen at the time the data were being prepared. Temperature and humidity were extracted at both 0000Z and 1200Z, then averaged to provide mean daily temperature and humidity. These values were also later interpolated to  $\frac{1}{4}$ -day intervals. Geostrophic currents were calculated from a temporally constant ocean dynamic height field (S. Levitus, pers. comm., 1981). Finally, all

external fields were spatially interpolated to the 40-km model grid.

Of interest here are the SLP fields that were obtained from the NCC; they will be referred to as the NCC fields. These objective analysis fields, used in the October–November study, were generated by the National Meteorological Center (NMC) optimal interpolation analysis program (OI) before they were archived at the NCC. They were also listed as being the “final” analysis production run, signifying that it is the last analysis for the indicated time, with the data cutoff period being 10 hours after that nominal time. Both the generating program and production run marker are included with each data field on tape. Although the data were manually examined, no detailed examination of the SLPs or their respective winds was carried out before they were used to drive the model. As a result, this investigator proceeded to make substantial conclusions concerning the sensitivity of ice to the wind and current fields in that study (Tucker 1982), assuming that the NCC fields were as reasonable as any available. Moreover, the predicted drift of a buoy located on an ice floe appeared to agree with the observed drift (discussed below), leading the author to believe that the wind fields were adequate. In a subsequent investigation, to determine the reasons behind a very poor simulated trajectory of another buoy located closer to the ice edge, a more detailed analysis of the wind fields showed them to be suspect. This report demonstrates, by comparing different SLP analyses, how the modeling results can be severely distorted by using improper wind fields.

I am not aware how widely used the NCC–SLP data may be for other types of investigations. These data have, however, been included in the FGGE Data Catalogue as part of the level III-a FGGE (First GARP [Global Atmospheric Research Program] Global Experiment) data set. The findings of this study may then be useful to others contemplating data sources for such investigations as mesoscale wind-driven ocean models, particularly if the model grid is located adjacent to a high-relief orographic area.

## DESCRIPTION OF STUDY

For this study, 60-day simulations for the October–November 1979 time period were run on a 40-km grid,  $21 \times 31$ . The domain of this grid is smaller than that used in the Tucker (1982) study so less computer time is needed for the simulations while still showing significant effects of various

wind fields. The model grid, along with solid and free boundaries (through which inflow and outflow is allowed), is shown in Figure 1.

The 60-day average SLP fields and their associated geostrophic wind fields for three different analyses are shown in Figure 2. The digital data, obtained from the NCC and prepared as described previously, are shown in Figure 2a. The Northern Hemisphere surface analysis charts (SA) for this period were prepared by the NMC and were also obtained from the NCC. The SLPs in the region of the grid were digitized from copies of the 1200Z charts and spatially interpolated to the model grid. Geostrophic winds were then calculated. These fields are shown in Figure 2b. The difference between the preparation of the SA analysis and the NCC digital analysis is that, for the most part, the SA is constructed manually by experienced analysts who use a combination of reported station SLPs and satellite imagery. On the other hand, the NCC analysis fields are prepared completely by computer using a complex data assimilation scheme (McPherson et al. 1979) to update the model fields by applying the OI procedure, all the while maintaining the fields in the atmospheric model terrain-following sigma coordinate system. This procedure avoids errors and the computation time required to interpolate the model fields to isobaric surfaces (or sea level), update the model fields, and then interpolate back to the sigma coordinate system. However, to produce the SLP grid that is archived at NCC, a pressure reduction from the lowest sigma level to sea level is required for grid points that are not over ocean areas.

Figure 2c shows an independent analysis carried out by Thorndike and Colony (1979) in which SLP data from 70 high-latitude land stations and an array of FGGE buoys drifting in the Arctic Basin were used. These data were interpolated to a  $2^\circ$  latitude by  $10^\circ$  longitude grid using a similar OI procedure, but applied strictly at sea level. This will be called the TC analysis.

The comparisons show very distinct differences, particularly between the NCC and the other two analyses. The NCC analysis shows a large pressure gradient parallel to the Greenland coast resulting in a narrow band of very high velocity winds along the coast, which tended to transport the ice at high velocities in the previous simulations (Tucker 1982). Although orographic features can be expected to influence pressure and wind fields (Smith 1982), the effect should not be as great as is observed here. In contrast, the SA and TC fields appear to agree well in this 60-day averaged field and do not exhibit a large coastal gradient.

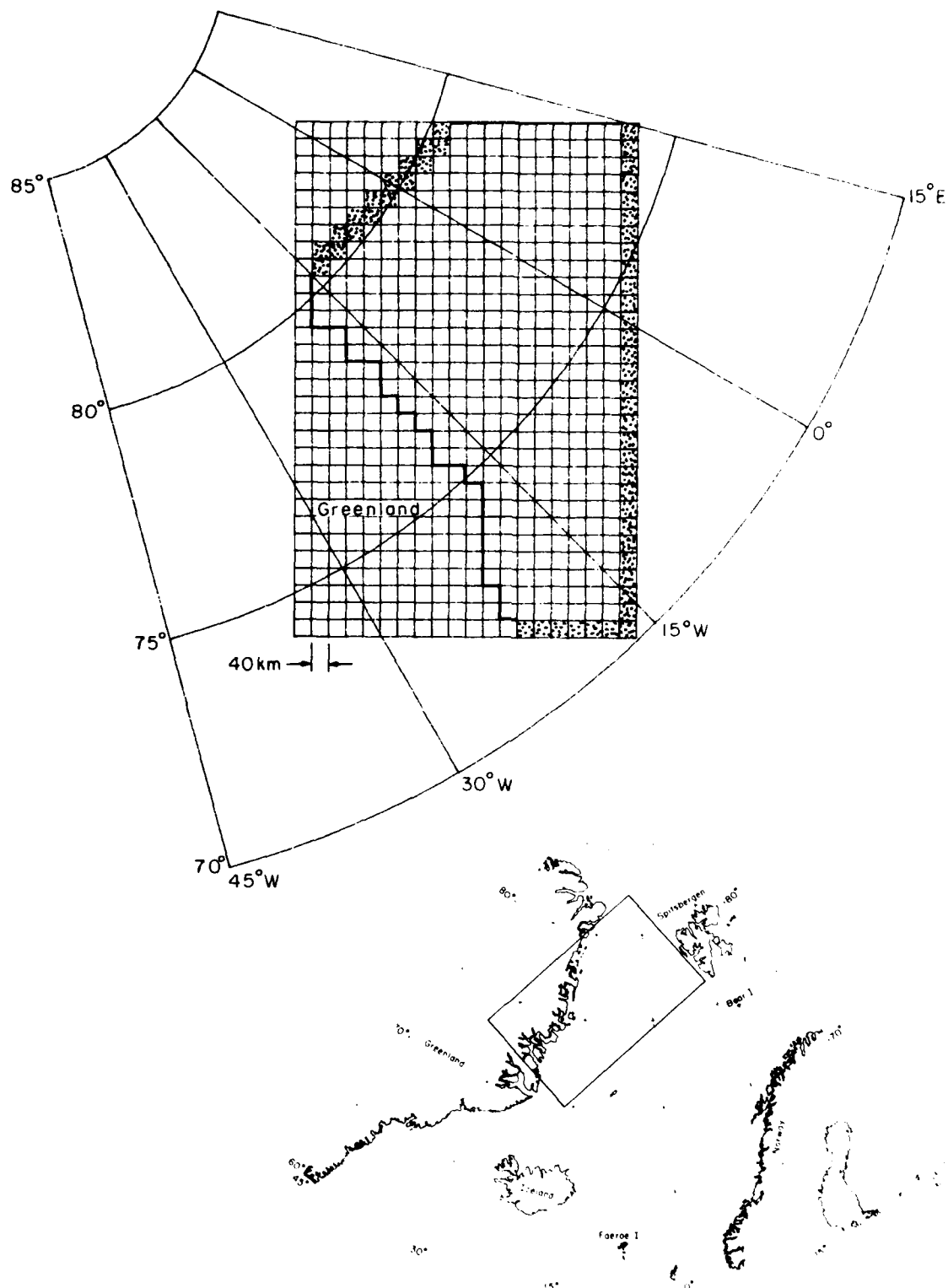
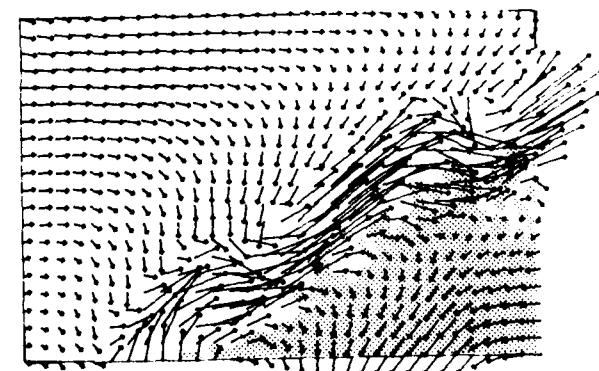
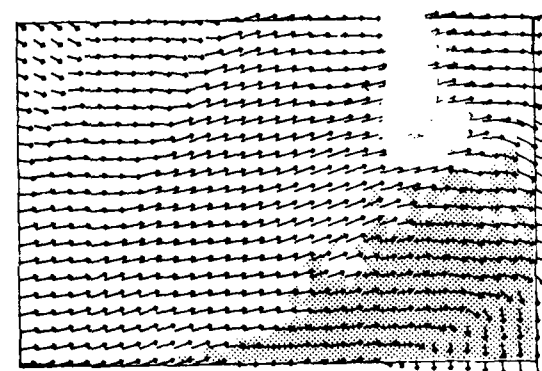
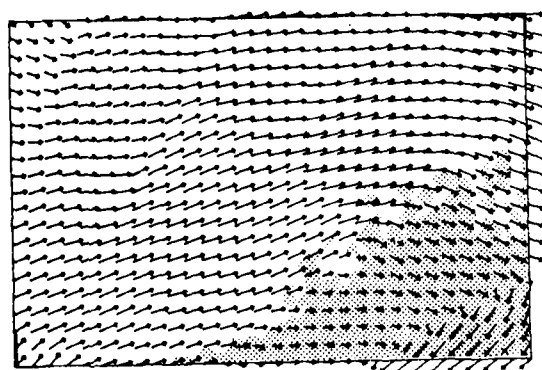
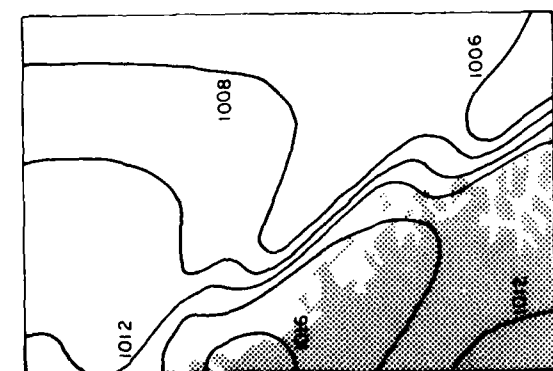
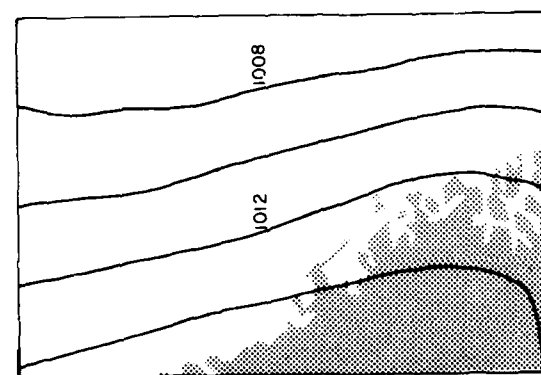
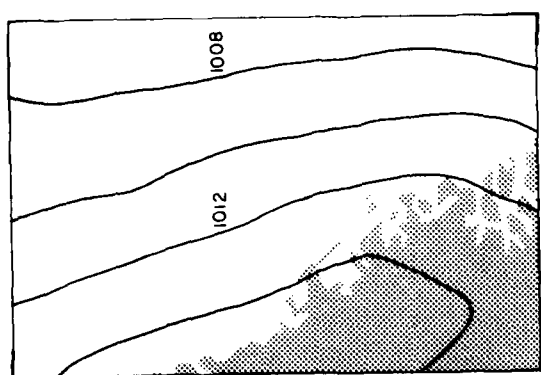


Figure 1. The model grid with solid and free (shaded) boundaries.

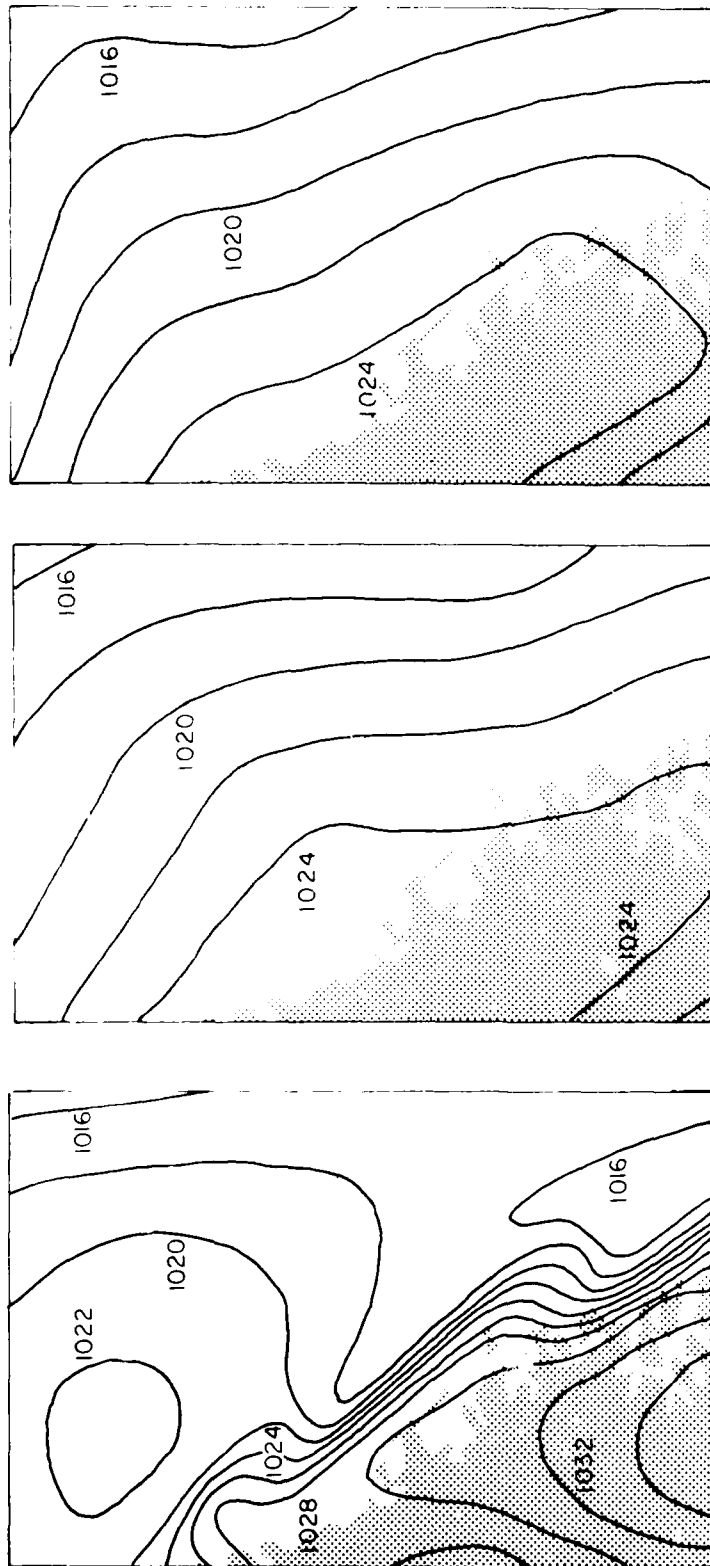


a. National Climatic Center (NCC) analysis.

b. Surface analysis (SA).

c. Thorndike and Colony (TC).

Figure 2. Sixty-day average sea level pressure (contour interval is 2 mb) and resulting winds.

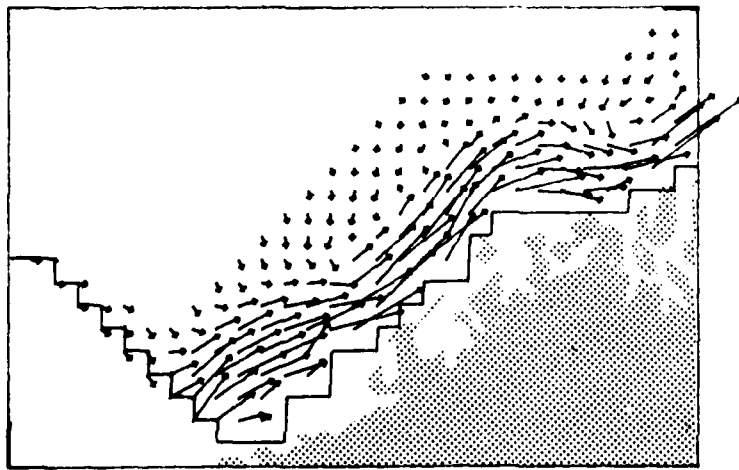


a. NCC analysis.

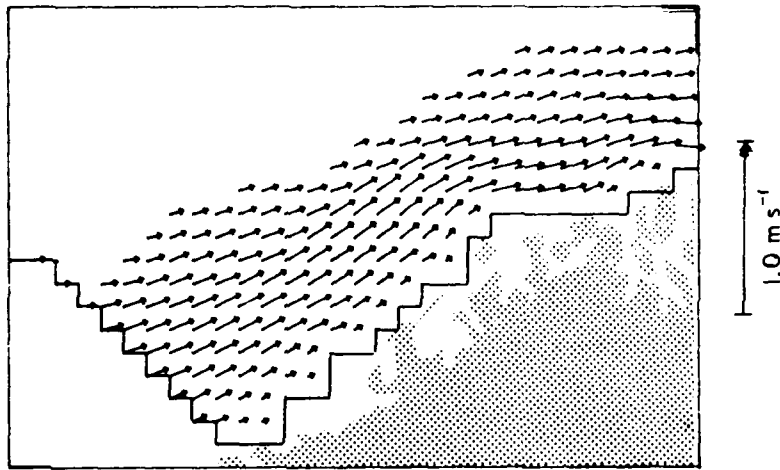
b. S.A.

c. TC.

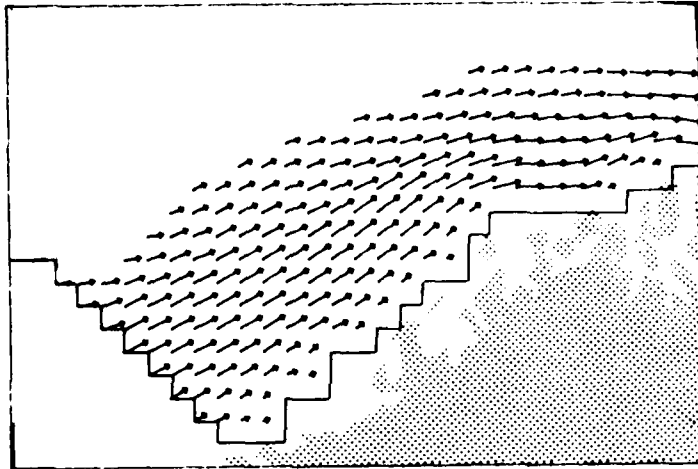
Figure 3. Sea level pressures (contour interval is 2 mb) for 1200Z, 15 October 1979.



*a. NCC simulation.*



*b. SA simulation.*



*c. TC simulation.*

*Figure 4. Sixty-day averaged ice velocities.*

Figure 3, which shows the SLPs for the three different analyses at 1200Z on 15 October 1979, is a specific example of the problem. Here the SA and TC analyses are very similar, but the NCC analysis shows a distinctly different pattern. As expected, its SLP gradient is quite large adjacent to the Greenland coast. In addition, the high over Greenland (1032 mb) is much higher than that evident in the SA or TC analyses (1024 mb). This example, while appearing to be somewhat extreme, is typical of more than 50% of the daily SLP fields for the 60-day model study period, as verified by the 60-day average pressures shown in Figure 2.

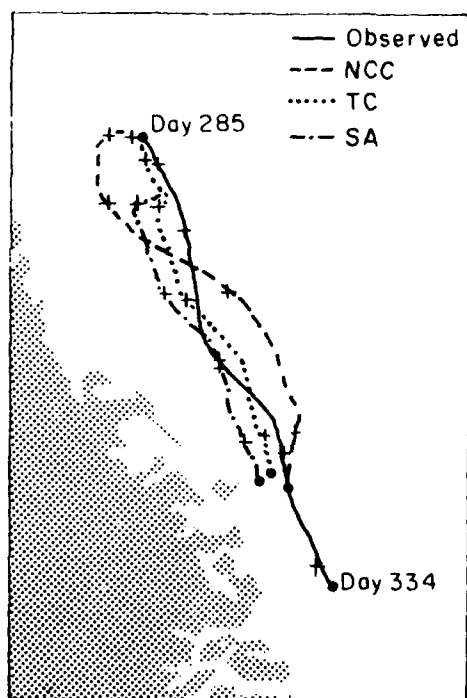
### MODEL RESULTS

The results of the 60-day model simulation using geostrophic winds calculated from the three independent analyses are discussed in this section. For these runs, the model thermodynamics were suppressed, allowing no growth or decay of ice. The dynamics-only simulations, driven externally by winds and currents, are sufficient to show the

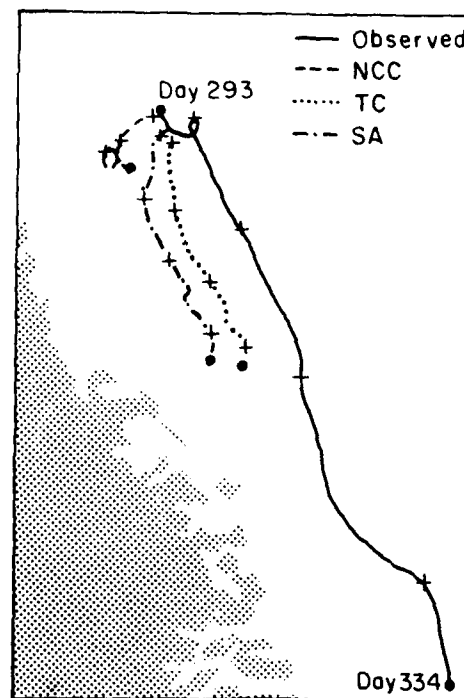
effects of the different wind fields. Currents were calculated as mentioned previously.

Figure 4 shows the 60-day averaged ice velocity fields for the three simulations. As expected, the NCC simulation shows large ice velocities in a very narrow band adjacent to the coast. Velocity fields for the SA and TC simulations agree with each other but, like the wind fields, depart significantly from the NCC-simulated velocities. These fields show general ice drift southward along the coast, but without the large shear evident in the NCC velocity field.

The accuracy of the simulated velocities can be assessed by comparing them to buoys that were drifting on ice floes during the study period. Figure 5 shows the observed trajectories and simulated cumulative drifts for Norwegian Remote Sensing Experiment (NORSEX) buoys 1564 and 1568 (Kloster and Rafto 1980). Buoy 1564 (Fig. 5a) was located well inside the ice margin, and all simulations provide similar trajectories, particularly with respect to final position. Because the NCC simulated trajectory appeared to be reasonable, the author had assumed that the NCC winds

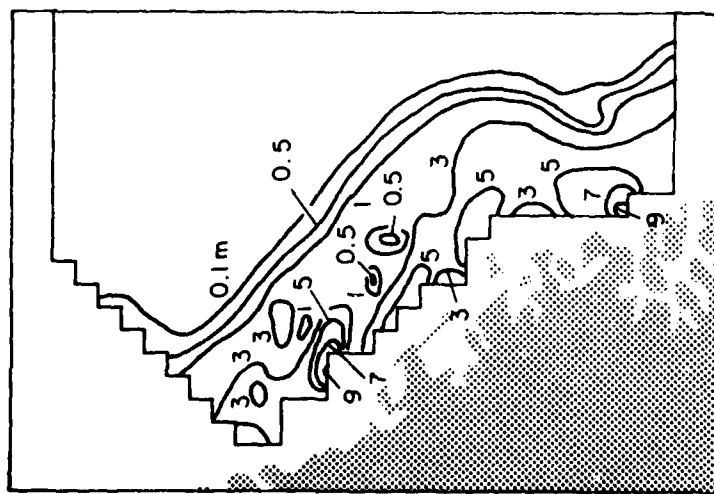


a. Buoy 1564.

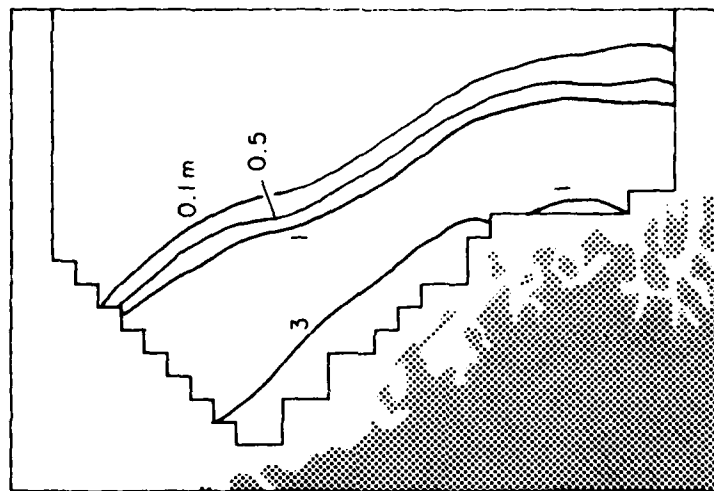


b. Buoy 1568.

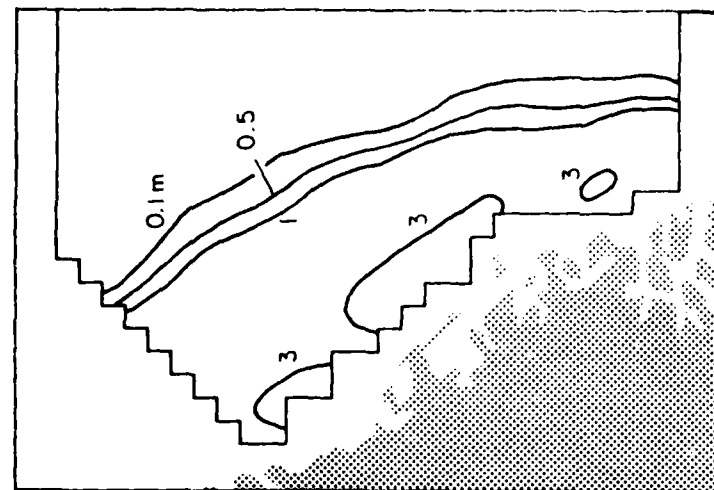
Figure 5. Observed trajectory and simulated cumulative drift for NORSEX buoys. Crosses are plotted at intervals of 10 Julian days (i.e. 290, 300, etc.).



a. NCC simulation.



b. SA simulation.



c. TC simulation.

Figure 6. Sixty-day averaged ice thickness fields.

**Table 1. Correlation coefficients and RMS errors between simulated and observed daily buoy velocities and volumes of inflow and outflow for each simulation.**

Simulation	Buoy 1564				Buoy 1568				Northern inflow (10 <sup>6</sup> km <sup>3</sup> )	Southern outflow (10 <sup>6</sup> km <sup>3</sup> )
	Corr. coeff.		RMSE (m s <sup>-1</sup> )		Corr. Coeff.		RMSE (m s <sup>-1</sup> )			
	u	v	u	v	u	v	u	v		
NCC	0.44	0.49	0.13	0.14	0.44	0.43	0.23	0.36	5.43	2.48
TC	0.69	0.73	0.07	0.10	0.49	0.40	0.18	0.29	3.95	0.99
SA	0.66	0.68	0.08	0.10	0.52	0.56	0.19	0.29	3.78	1.14

were sufficient. A closer inspection of the cumulative drifts for this buoy, however, emphasizes that the NCC simulated drift is less accurate than the SA and TC simulations because there is almost always more lateral distance error. In addition, the final position is similar to the other simulations only because the NCC simulated drift is very rapid for the last 15 days. Before that, the SA and TC drifts have much less position error.

For buoy 1568, none of the simulated final positions is satisfactory, but the SA and TC simulated drifts are far superior to the NCC simulation. This buoy was located very near the free ice edge; in the NCC simulation, it was often located in the areas of very low ice velocities that are evident in the 60-day averaged velocity fields (Fig. 4a). As a result, its simulated trajectory is very poor. Improved current fields may provide more satisfactory results for all simulations.

The final 60-day averaged ice thickness fields are shown in Figure 6. In the NCC simulation (Fig. 6a), some of the areas of increased thickness adjacent to the coast have three times the average thickness of those in the SA or TC simulations. These result from the deforming of ice by ridging due to the significantly higher wind forcing in the NCC simulation. The thin ice areas farther offshore in the NCC simulation are due to local divergence, resulting from the advection of ice out of an area more rapidly than it can be replaced. Another interesting point is that the ice extent is somewhat greater in the SA and TC simulations. This is attributable to their more uniform wind fields (Fig. 2), which advect ice further to the east.

A summary of the results from the three simulations is given in Table 1. Here the *u* and *v* velocity correlation coefficients between simulated and observed buoy velocities show that, in general, the TC and SA simulations were superior. Since the correlation coefficient is capable of providing information only about the high-frequency components of velocity—that is, the daily fluctuation—

the root mean square error (RMSE) is also presented. These values also show that the SA and TC simulations are indeed superior for the buoy velocities. Even for buoy 1564, it is clear that, although the final position was simulated as well by the NCC simulation as by the others, the overall velocities are superior for the SA and TC simulations.

The table also shows the volumes of ice that flowed in through the northern free boundary and out of the southern boundary. The effect of the high winds generated by the NCC analysis is clearly seen by the volume of ice transported. Although northern inflow is much higher for the NCC simulation, much larger differences are apparent in the southern outflow, where the total volume for the NCC simulation is more than twice as large as those of the other simulations. This is a critical difference; by assuming that the NCC-derived winds were correct, I was led to conclusions in an earlier study (Tucker 1982) about the transport of ice by winds and current during this period that require modification. This reassessment is currently being carried out and although it appears that winds remain the major driving force, they are much less important than previously thought.

## THE PROBLEM

The problem with the NCC data appears to be partially one of pressure reduction (J. McDonnell, R. McPherson, pers. comm., 1982). As discussed earlier, the assimilation procedure consists of interpolating variables (using the OI procedure) to appropriate layers of the sigma coordinate system. In this manner, the geopotential height of an isobaric surface is not required. Values of pressure at the lowest sigma level (the surface) are required, however; and a two-dimensional OI procedure merges the first-guess field (a model forecast) and the station reports to form the grid values

(McPherson et al. 1979). To obtain sea level pressures then requires that a pressure reduction procedure be applied to that portion of the grid that is not at sea level.

To obtain the pressure reduction equation, we must first use the hydrostatic equation:

$$(\partial p / \partial z) = - \rho g \quad (1)$$

where  $p$  = atmospheric pressure  
 $z$  = height  
 $\rho$  = air density  
 $g$  = gravitational acceleration.

Substituting for  $\rho$  using the equation of state for moist air and rearranging:

$$(\partial p / p) = (g \Delta z / R \bar{T}^*) \quad (2)$$

where  $R$  is the universal gas constant and  $\bar{T}^*$  is the virtual temperature. Integrating in the vertical from sea level to some height  $z$  we obtain:

$$p_{sl} = p_z \exp[(g_z \Delta z) / (R \bar{T}^*)] \quad (3)$$

where  $p_{sl}$  = sea level pressure  
 $\Delta z$  = change in height between sea level and  $z$   
 $\bar{T}^*$  = mean virtual temperature of the assumed layer of atmosphere.

The two unknowns in eq 3 are  $p_z$  and  $\bar{T}^*$ . The major problems encountered with this procedure are generally associated with  $\bar{T}^*$ . In our case, the procedure would be applied over Greenland; since there are very few reporting stations in this region, atmospheric model forecasts would be used to provide  $p_z$  and  $T_z^*$ , the pressure and virtual temperature at the lowest sigma level. The temperature is likely to give the most error. Because Greenland is a high-elevation (> 2500 m) mass of snow and ice, a mean temperature for an assumed layer of atmosphere here, which depends upon the model forecast surface temperature, is almost certain to be too low. Equation 3 gives a sea level pressure that is too high when this is the case. Both Figures 2 and 3 show that NCC pressures are higher over Greenland than those in the TC and SA analyses.

An associated problem is the low pressure trough just offshore, which in combination with the excessive high pressure over Greenland produces the large pressure gradient in the NCC analysis. This may result from a spectral filter applied to the terrain field, which undergoes a large change in elevation at this location (McPherson,

pers. comm., 1982). The response function of such a smoothing filter to a step function (as the rapid change in elevation of eastern Greenland may appear) may be expected to cause a trough of this nature. This hypothesis seems plausible because the average SLPs in the eastern corner of the model grid for all three analyses compare reasonably well (Fig. 2). Only in the region of large topographic gradients does the NCC analysis differ from the other two.

In contrast, no large-scale pressure reduction or spectral filtering operations were involved in the SA and TC analyses. Pressure reduction was applied only in the case of individual stations not situated at sea level. Both analyses were then carried out at sea level, one (TC) being an automatic OI scheme and the other (SA) done manually by experienced analysts with the aid of other data sources. The important difference is that these analyses originally were made with sea-level data, not in a terrain-following coordinate system that later had to be reduced to sea level.

## CONCLUSIONS

This limited-area study of ice modeling in the Greenland Sea has shown results using geostrophic winds calculated from three different sources of sea level pressure. Results using winds obtained from a manual SLP analysis (SA) and from an optimal interpolation procedure applied to a combination of drifting buoys and high-latitude land stations (TC) agree favorably. An analysis derived from the NMC data assimilation system (NCC), which required a pressure reduction procedure to arrive at sea level from the lowest sigma level, produces a geostrophic wind field that yields significantly different model results. This analysis predicts a narrow band of high-velocity winds (60-day average) that significantly affect ice transport in this region. Ice deformation and resulting thickness fields also appear to be unrealistic. Although ocean currents are not well represented in the model—which probably accounts for the insufficient total buoy displacement in the simulations—daily velocities are well predicted using winds derived from the TC and SA pressure fields. Total ice transport during the October–November 1979 study period is also significantly reduced using these latter two analyses.

The point here is not to criticize the NMC analysis scheme. The automatically generated SLP fields are created as a small by-product of a complex updating procedure for the global atmos-

pheric modeling system. The "official" SLP analysis is done primarily by hand by experienced analysts and, as the results of this study show, seems to be quite reasonable in this complex, data-sparse area. Rather, the warning here is that data fields should be carefully examined before this type of modeling study is undertaken. In the case of SLP that may be used to drive an ice or ocean model, particular care should be taken in ocean areas adjacent to high topographic features.

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